A Compact Fusion Device based on the Sheared Flow Stabilized Z-Pinch*

Uri Shumlak for the FuZE Team

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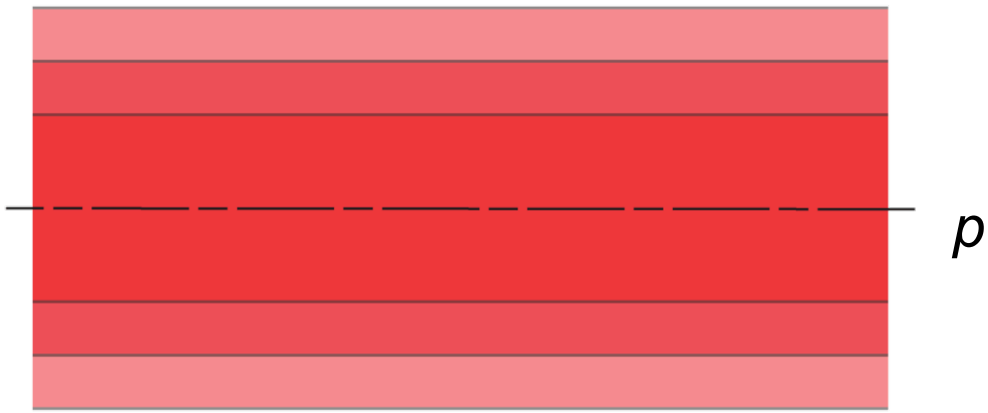
Presentation Outline

- The simplicity and many other advantages of the Z-pinch
- Historical scientific development leading to our sheared flow stabilization approach − SFS Z-pinch
- ARPA-E-funded FuZE, Fusion Z-pinch Experiment, and the development path for the SFS Z-pinch
- Recent alignment of critical factors that make now the right time to advance the SFS Z-pinch as a compact fusion reactor

Z-pinch configuration has many appealing features

The Z-pinch has the simplest geometry of any magnetic confinement configuration:

- cylindrical plasma column



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The Z-pinch has the simplest geometry of any magnetic confinement configuration:

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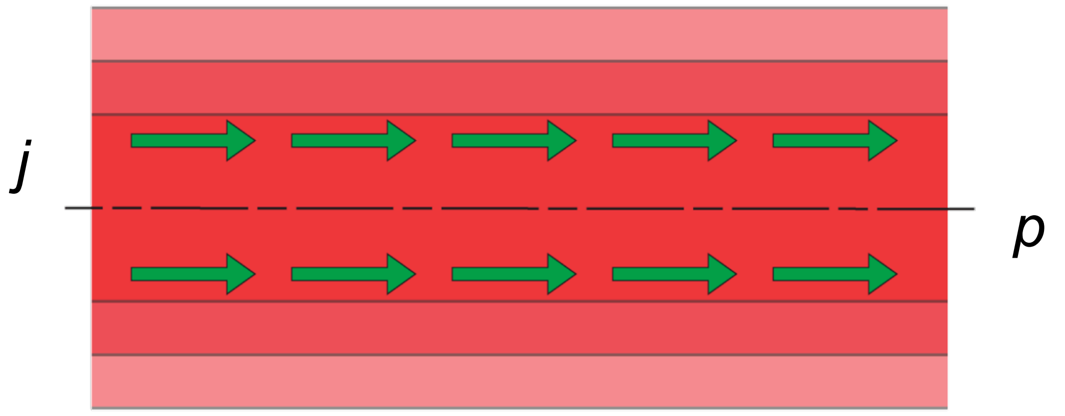
- directly driven axial current



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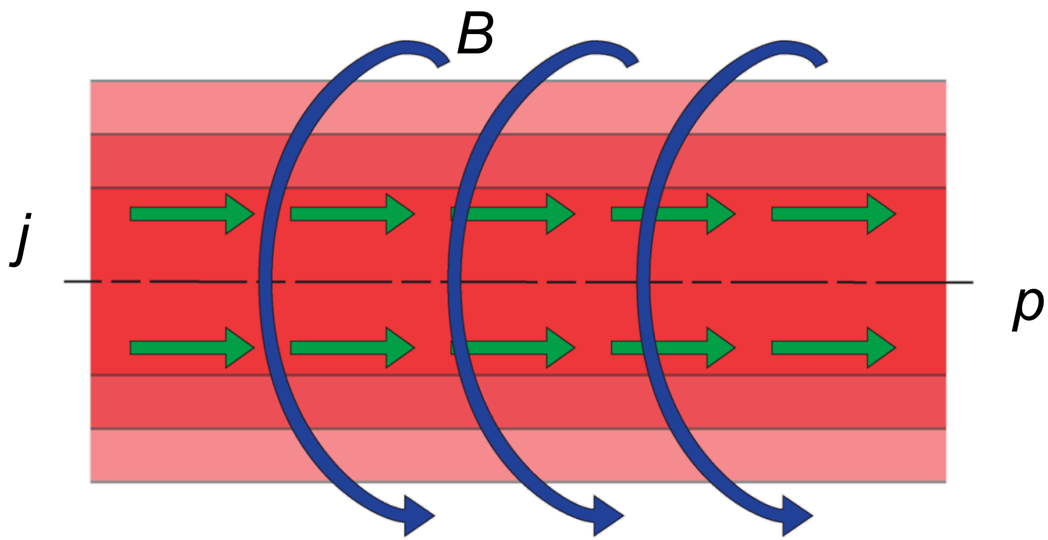
- directly driven axial current
- self-generated magnetic field compresses the plasma

$$\frac{dp}{dr} = -\frac{B}{\mu_o r}\frac{d(rB)}{dr}$$



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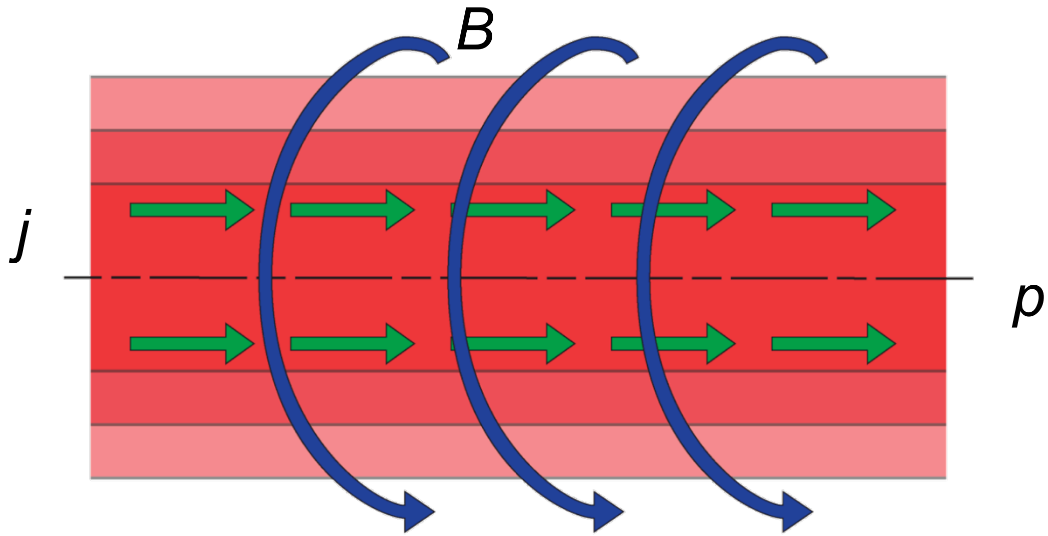
- cylindrical plasma column
- directly driven axial current
- self-generated magnetic field compresses the plasma
- ➢ perfect utilization of the magnetic field for compression, β=100%
- ➢ no magnetic field coils: greatly reducing cost, size, and complexity
- ➢ increasing the current generates higher plasma parameters, increased fusion production, and smaller plasma radius



Z-pinch research predates nuclear fusion understanding

1790: Earliest “Z-pinch” research by Martinus van Marum

1905: Observation of crushed lightning rod by Pollock & Barraclough

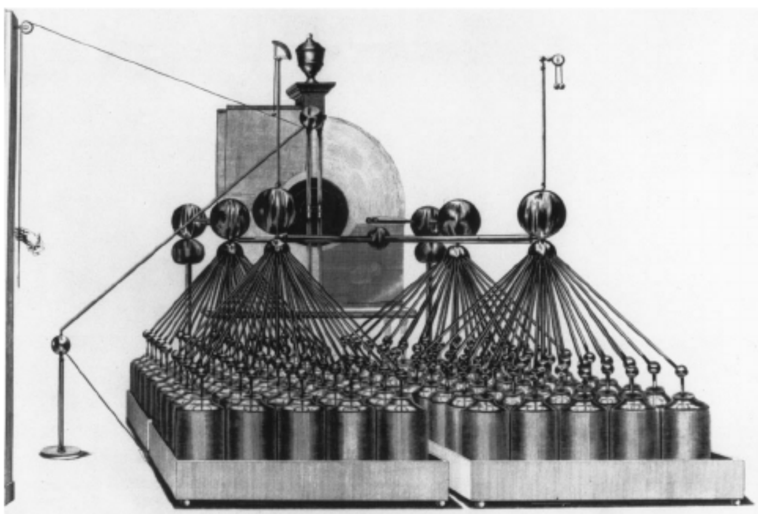
1907: “Pinch phenomenon” in liquid conductor by Northrup

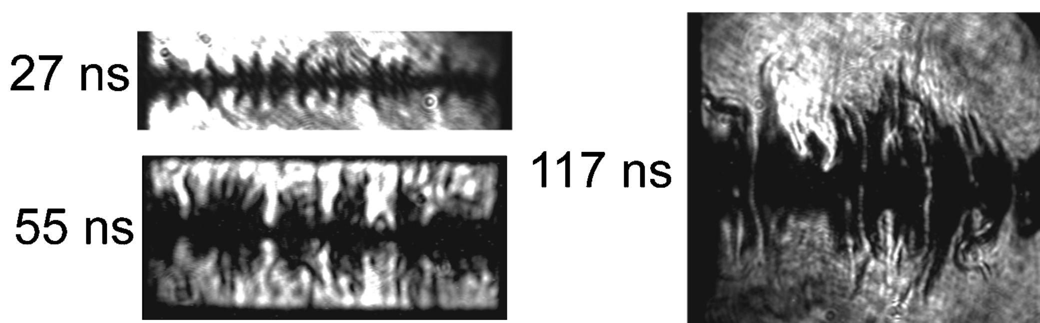
1934: Theoretical model of plasma Z-pinch by Bennett

1950: Z-pinch was Project Sherwood Jim Tuck’s preferred approach to achieve controlled fusion

1957: Theory and experiments demonstrated virulent instabilities, $m = 0, 1$

1998: Performance of Z-pinches using frozen deuterium fibers was severely limited by these instabilities





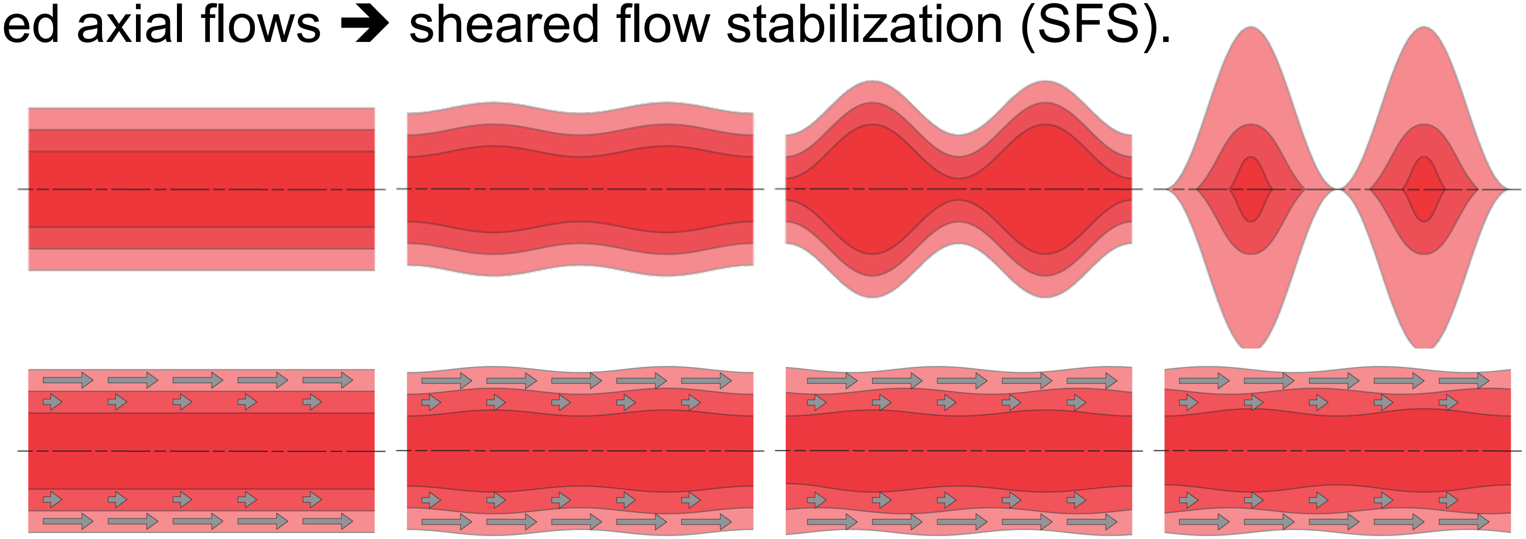
Key Innovation: sheared flows can stabilize the Z-pinch

- Prior theoretical and experimental research focused on static Z-pinch plasmas, and demonstrated that $m = 0$ and $m = 1$ instabilities persist.
- 1995: Theoretically demonstrated that a Z-pinch could be stabilized with low-speed axial flows ➔ sheared flow stabilization (SFS).

No flow

Sheared flow

$$\frac{dv_z}{dr} \neq 0$$



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Sheared Flow Stabilization of the $m = 1$ Kink Mode in Z Pinches

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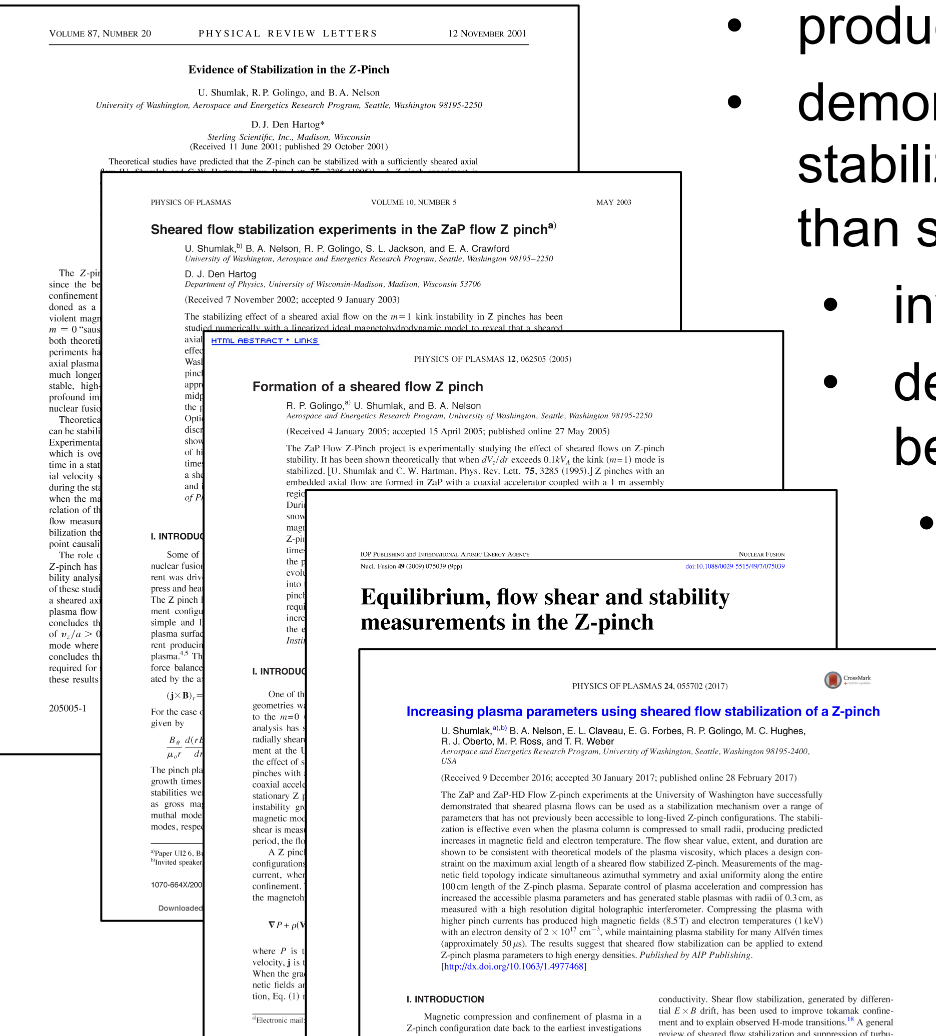
(Received 6 April 1995)

The effect of a sheared axial flow on the $m = 1$ kink instability in Z pinches is studied numerically by reducing the linearized magnetohydrodynamic equations to a one-dimensional displacement equation. An equilibrium is used that is made marginally stable against the $m = 0$ sausage mode by tailoring its pressure profile. The principal result reveals that a sheared axial flow stabilizes the kink mode when the shear exceeds a threshold that is dependent on the location of the conducting wall. For the equilibria studied here the maximum threshold shear (v_z'/kV_A^0) was about 0.1.

Scientific advancement of sheared flow stabilization

1998 – 2014: DOE-funded experimental project at the University of Washington <u>to conduct a scientific investigation of sheared flow stabilization in the Z-pinch</u> ➔ ZaP & ZaP-HD projects



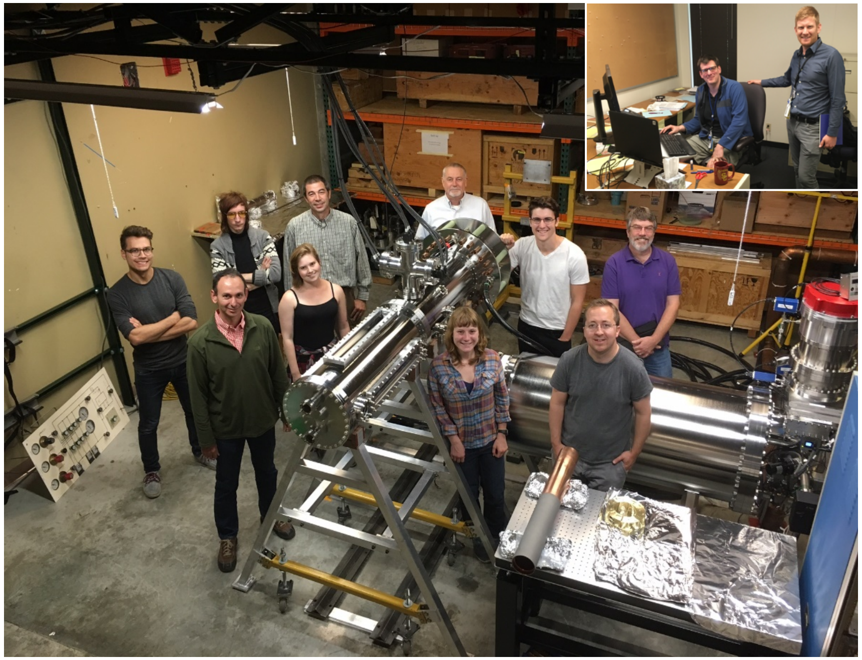
- produced long-lived, stable Z-pinch plasmas
- demonstrated robustness of sheared flow stabilization: stable for 1000's times longer than static pinch
    - investigated limits of stability
    - developed understanding of plasma behavior and how to control it
        - achieved pinch currents of 50 kA

FuZE Project is advancing the SFS Z-pinch for fusion

Sheared flows provide complete stability at moderate plasma currents.

- ➢ Will the stabilizing effect continue as current is increased?

ARPA-E ALPHA Program funded the UW/LLNL FuZE Project at ≈10x previous levels to explore the potential of the SFS Z-pinch as a compact fusion device.

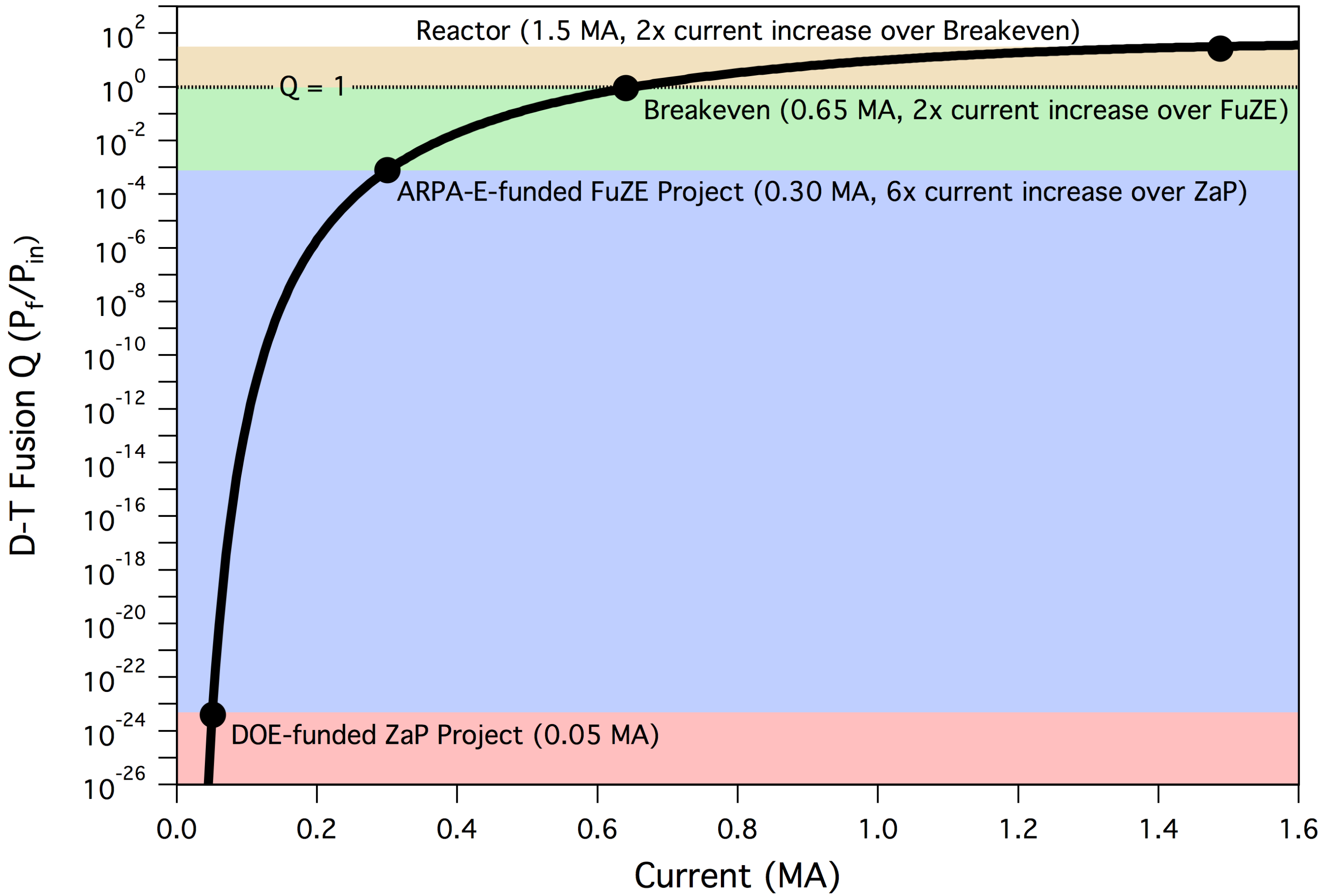


- incorporates LLNL’s scientific expertise and hardware
- builds on the success of our previous SFS Z-pinch projects

- ➢ to advance the SFS Z-pinch fusion concept to the next step along the development path.

Development path for the SFS Z-pinch fusion core

Increases in plasma current mark the key steps along the development path for the SFS Z-pinch fusion core.



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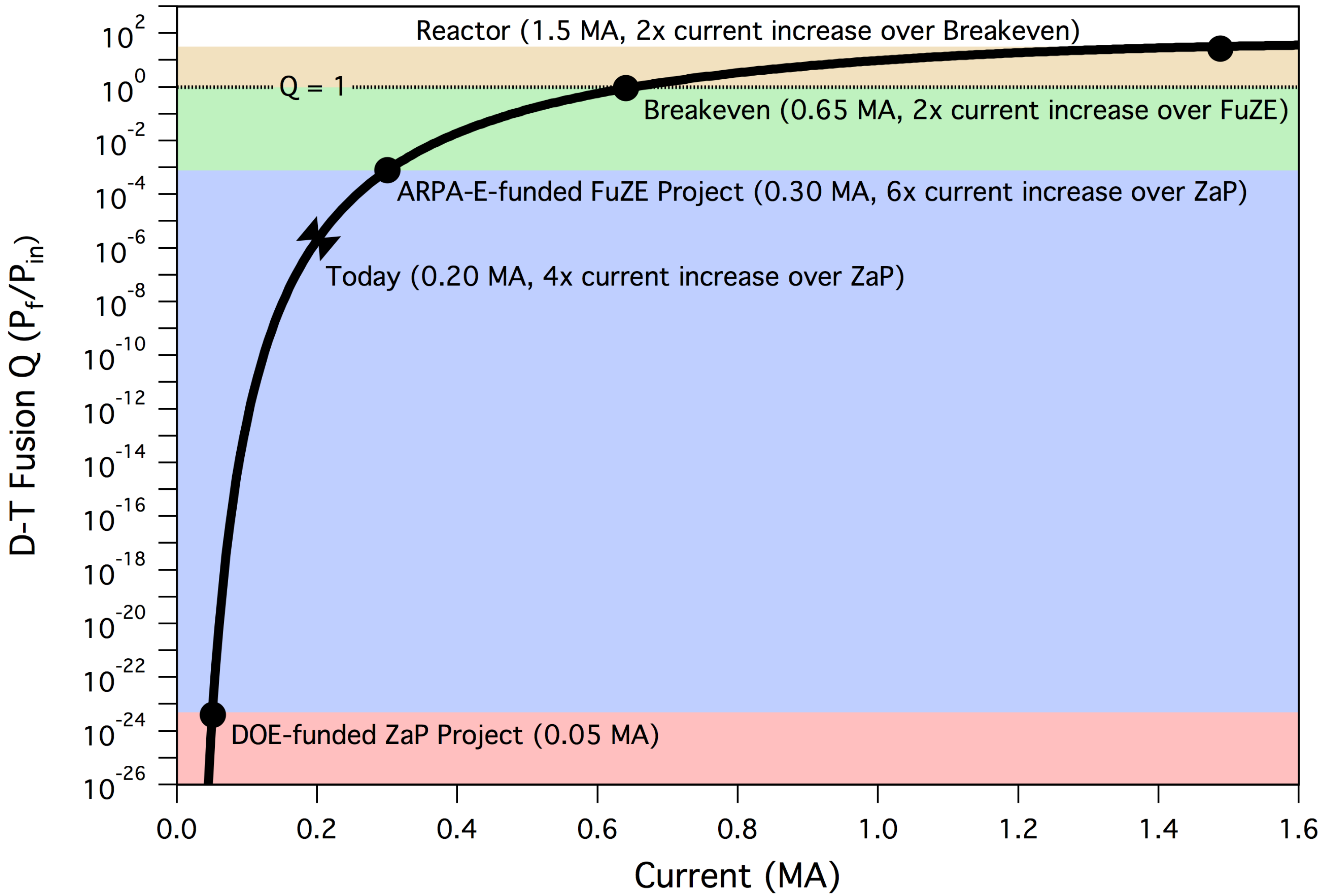
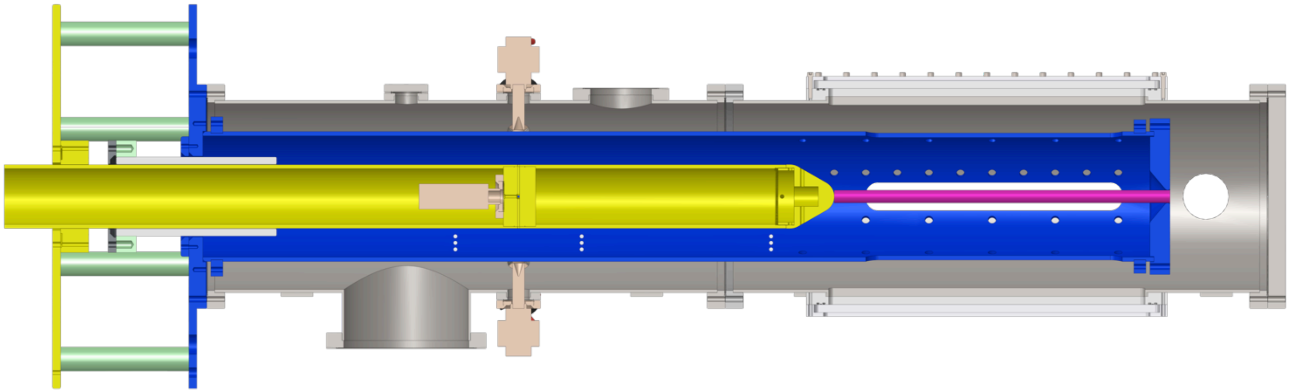


Now is the right time for SFS Z-pinch fusion

Four critical factors have converged:

1. ARPA-E funding has enabled us to push the SFS Z-pinch concept much further than previously possible, e.g. 6x current increase.
2. Computational power and simulation tools allow detailed modeling of sheared flow stabilization that support the experimental effort.
3. Encouraging experimental and computational results indicate sheared flow stabilization is robust even at higher currents. (Visit our technical poster for details.)
4. Growing recognition that a carbon-free power source is desperately needed and that current mainline fusion approaches are too costly and advancing too slowly to contribute to the solution.



ZAP ENERGY INC

RAISING SERIES A FUNDING

- <u>ZAP ENERGY INC was incorporated in May 2017 as a spin-out from the UW and LLNL, contact Benj Conway, reachout@zapenergyinc.com</u>
- <u>ZAP ENERGY is raising Series A funding to demonstrate breakeven</u>
- <u>Targeting a compact, commercial fusion application</u>
- Building on significant breakthroughs in fusion technology developed by UW and LLNL team since 2015
- Signed a proprietary intellectual property licensing agreement in June 2017
- ARPA-E funded until August 2018 after which ZAP ENERGY team to physically spin-out of UW onto new premises
- Team has over 90 years combined experience in fusion research
- Substantial advantages by removing the need for costly and complicated magnetic coils
- FuZE project equipment provided by UW to ZAP ENERGY on loan
- Substantially reduced risk through validation of technology with historical DOE grant funding and existing ARPA-E award, which provides funding through August 2018

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